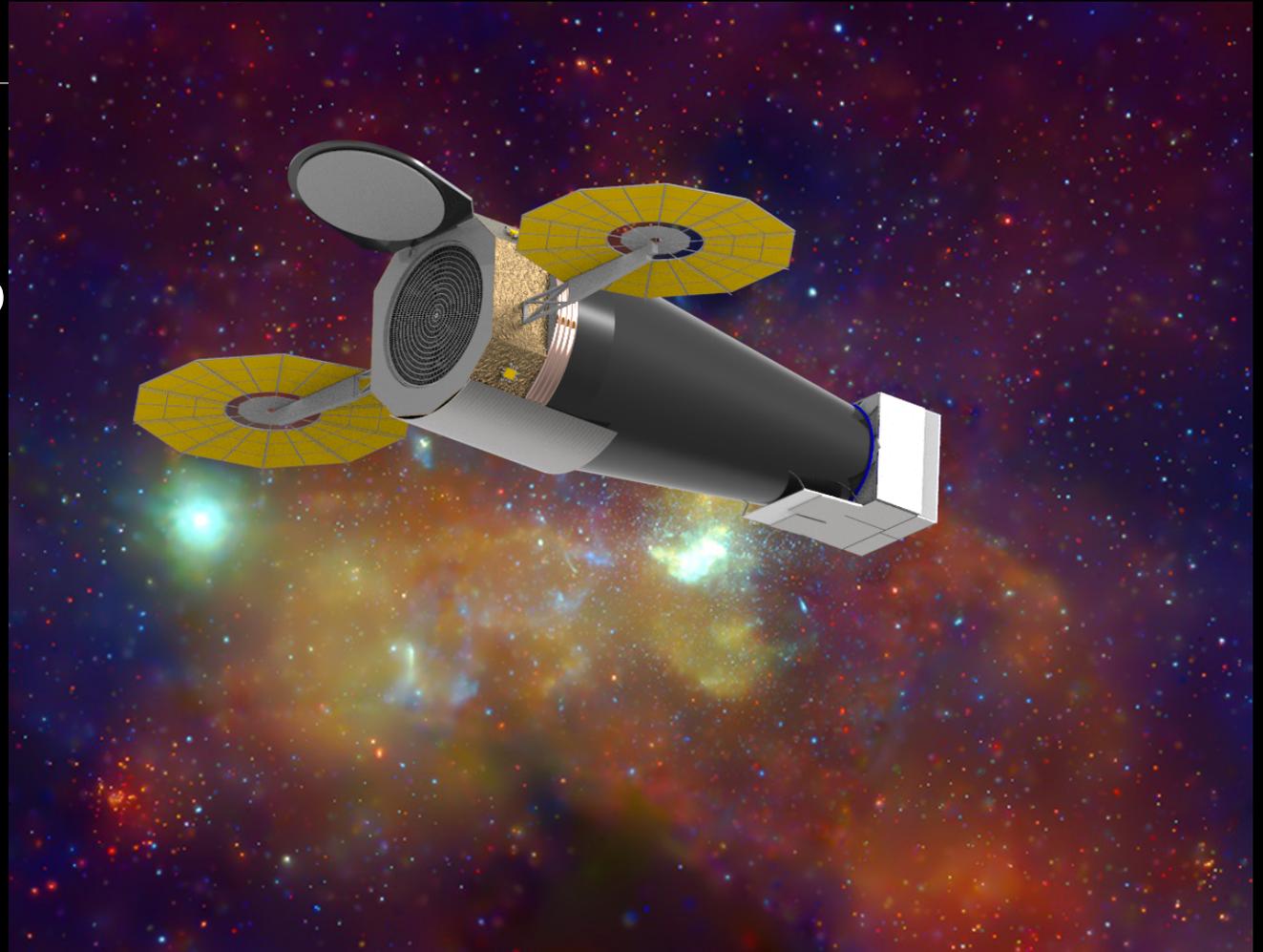




LYNX: OPTICS DEFINED

J. Gaskin, NASA MSFC

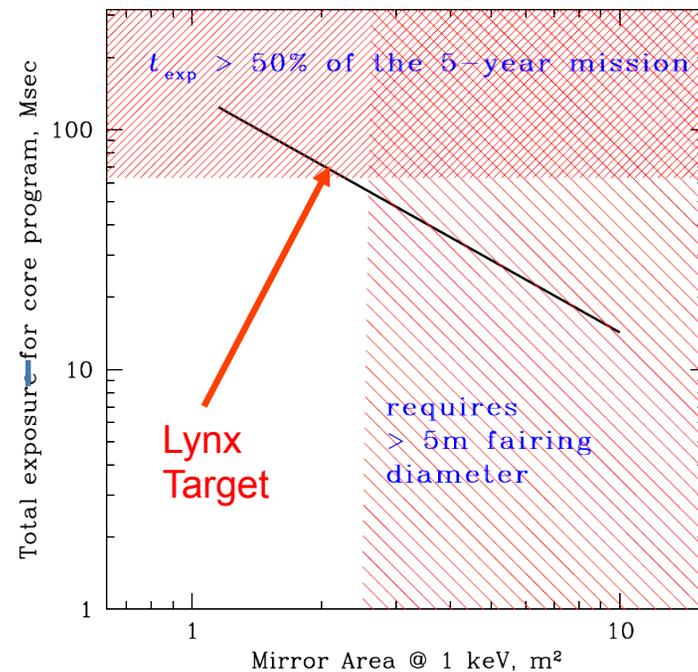
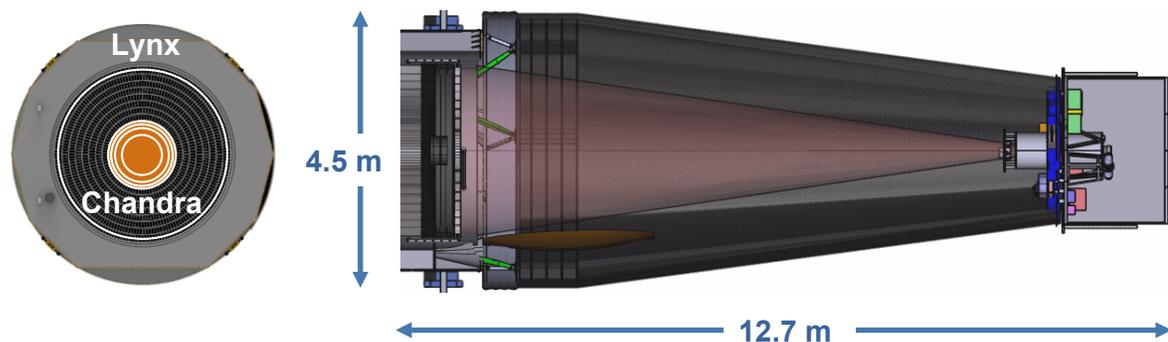
Presented on behalf of the Lynx
Optics Team





SCIENCE DRIVEN TELESCOPE CONFIGURATION

- 2 m² of effective area at E = 1 keV is required to execute the three science pillars in ~50% of the 5-yr mission baseline lifetime. **A goal of Lynx is to maximize discovery!**
- This is achieved with an outer diameter of 3-m with a focal length of 10-m.
 - Optimized for bandwidth, effective area, resolution/FOV



https://wwwastro.msfc.nasa.gov/lynx/docs/presentations/2017-06-07_MirrorResolutionPrimer_MShattenburg.pdf



MIRROR REQUIREMENTS

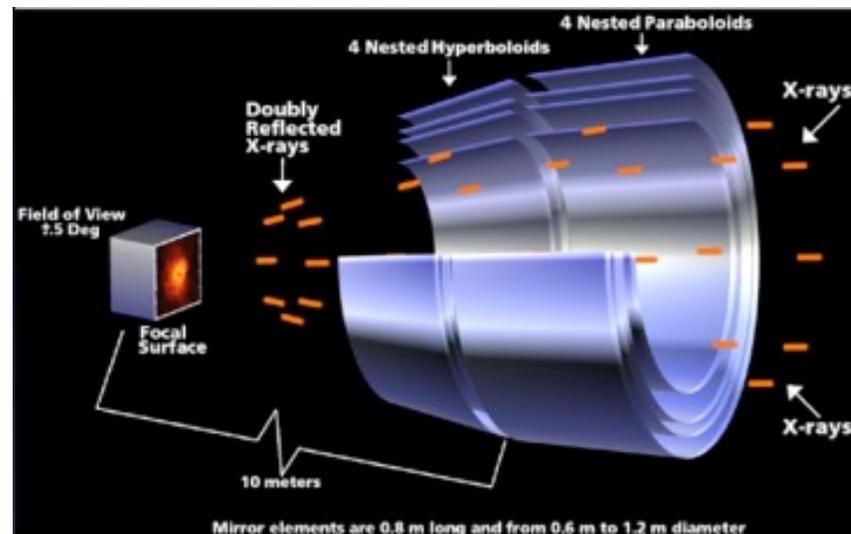
- **Large effective area** is achieved by nesting a few hundred to many thousands of co-aligned, co-axial mirror pairs.
- Must fabricate **thinner mirrors** to allow for greater nesting of mirror pairs to achieve larger effective area while reducing mass.
- These thin mirrors must be better than **0.5" HPD** requirement.
- Must **mount and coat** these thin optics **without deforming the optic**, or must be able to correct deformations.

Science Driven Requirements

Lynx Optical Assembly

Angular resolution (on-axis)	0.5 arcsec HPD (or better)
Effective area @ 1 keV	2 m ² (met with 3-m OD)
Off-axis PSF (grasp), A*(FOV for HPD < 1 arcsec)	600 m ² arcmin ²

Chandra did it! And so can Lynx!





LYNX MIRROR ASSEMBLY

FABRICATION

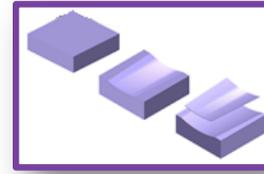
Thermal Forming
(GSFC, SAO)



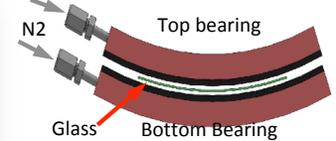
Full Shell
(INAF-Brera, MSFC, SAO)



Si Optics (GSFC)



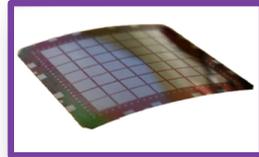
Air Bearing Slumping (MIT)



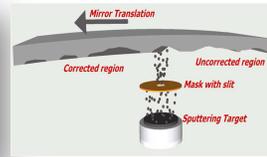
Testing/Simulation/Modeling

CORRECTION

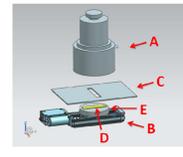
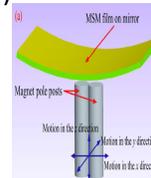
Piezo stress
(SAO/PSU)



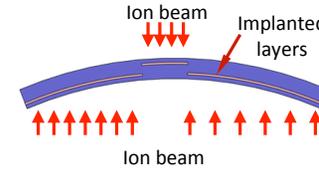
Deposition (MSFC, XRO)



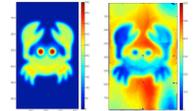
Magnetic & deposition stress (NU)



Ion implant stress (MIT)



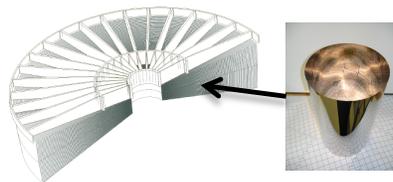
Ion beam figuring (OAB)



Testing/Simulation/Modeling

INTEGRATION

Full shells Assembly

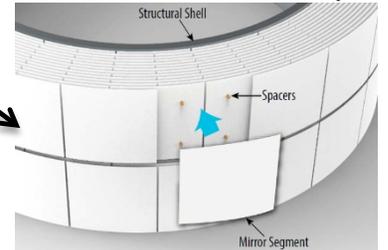


Segmented Wedge Assembly



Segments

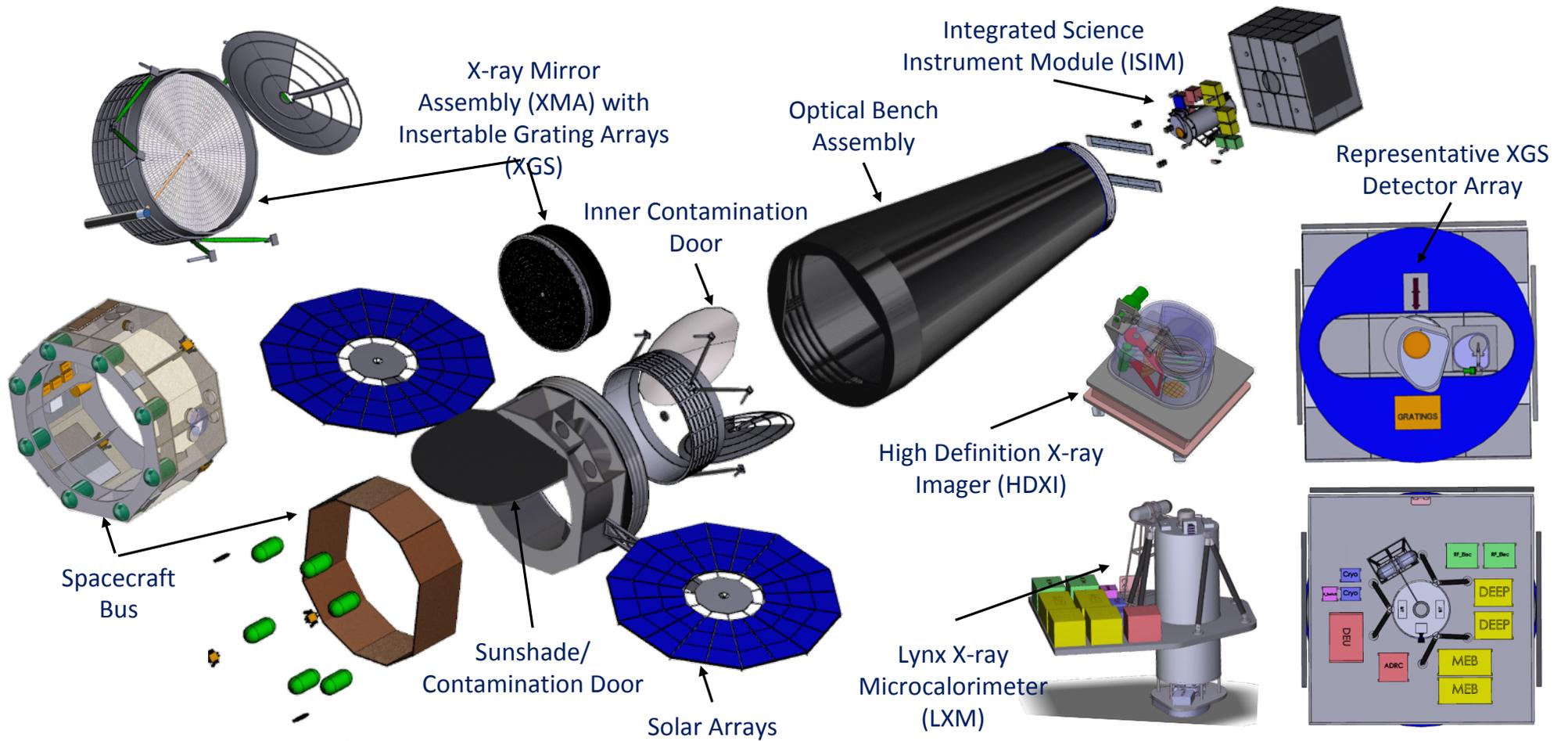
Meta-Shell Assembly



Testing/Simulation/Modeling



LYNX OBSERVATORY CONFIGURATION



Credit: NASA MSFC Advanced Concept Office



LYNX OPTICS TRADE STUDY – DRM SELECTION

- 3 actively funded Optics Technologies
- Kepner-Tregoe Trade Study chartered by Lynx STDT
- Facilitated by G. Blackwood (NASA JPL)
- Recommendation was made to STDT on 8/8/18

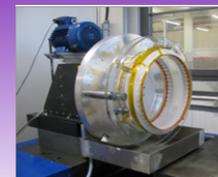
Executive Summary: Community working group conducted an open science, technical, and programmatic evaluation using public evaluation criteria in a series of telecons and F2F meetings that took place over 6 months (2018).

A broad consensus was reached on the recommendation and on the basis for the recommendation

- **Large and diverse team from industry, universities, and multiple NASA Centers**
- **~ 5,000 person-hours over 6 months**
- **~100 documents produced (~650 pages of material)**



Adjustable
Segmented (SAO)



Full Shell
(INAF-Brera/
MSFC)



Silicon Meta-Shell
(GSFC)

All 3 Optics Technologies are currently being funded by NASA, Institutional, Other funding!

Recommendation

The LMAT recommends the Silicon Meta-Shell as the DRM concept Mirror Optical Assembly Architecture to focus the design for the Final Report. Full-Shell and Adjustable Optics are determined to be feasible alternates.



LYNX MIRROR ASSEMBLY IN CONTEXT

1.2m Diameter



Chandra
(1999)

0.4m Diameter



NuSTAR
(2012)

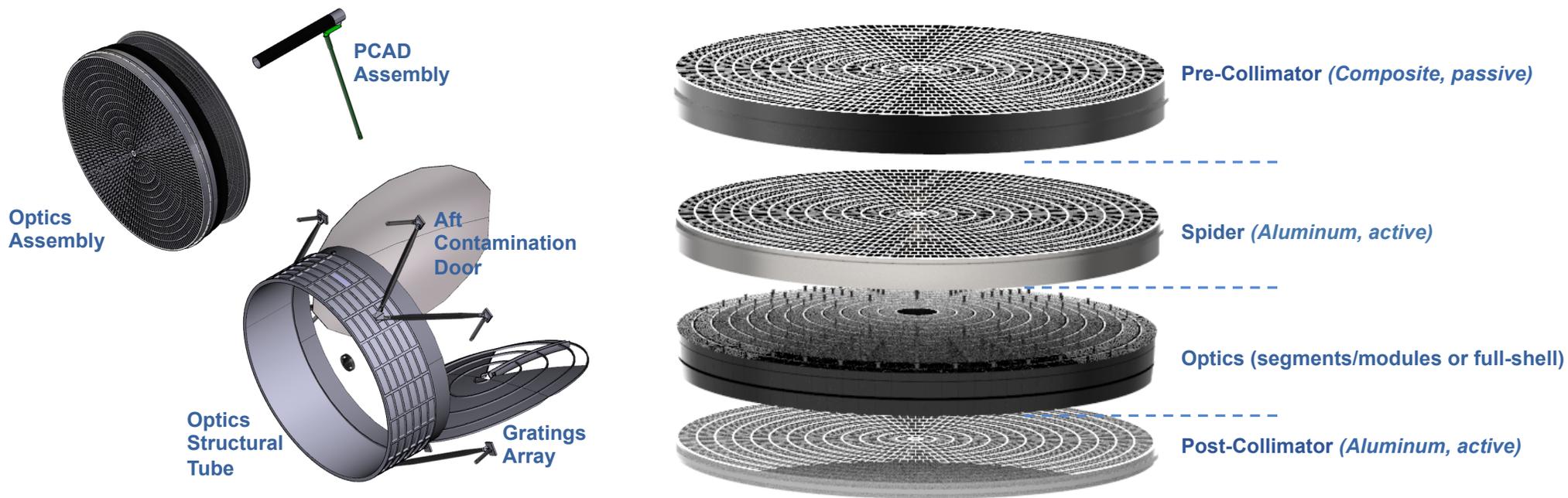
3.0m Diameter



Lynx
(mid-2030s)



OPTICS ASSEMBLY OVERVIEW

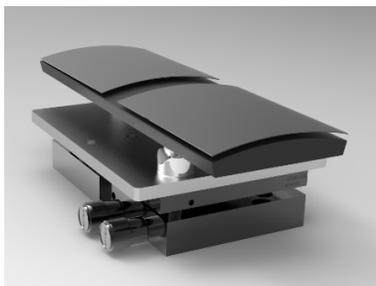




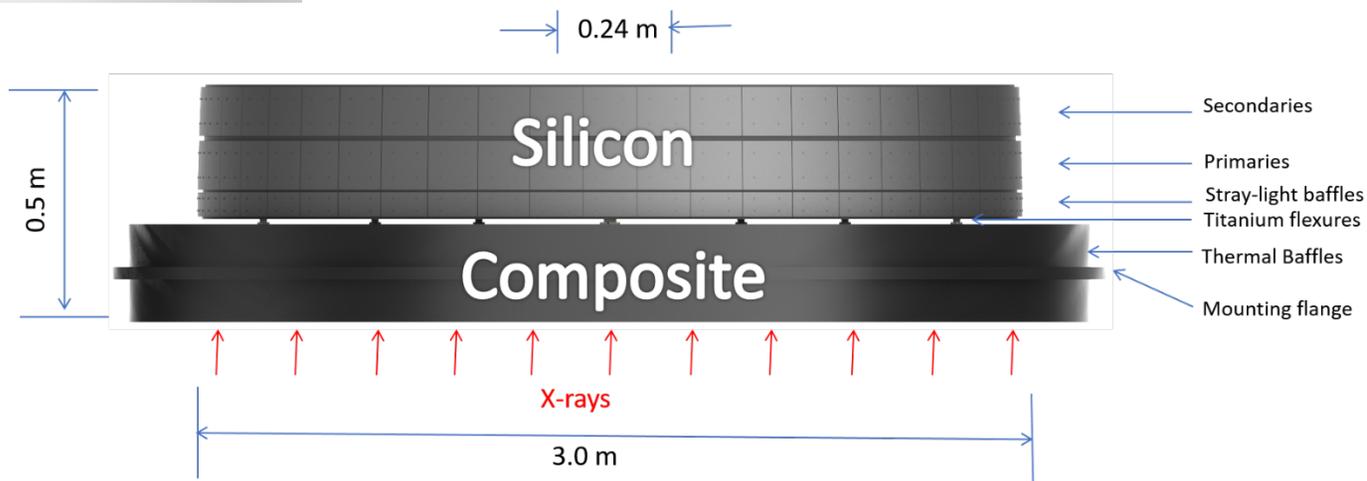
SILICON META-SHELL OPTICS

- W. Zhang & NGXO Team (NASA GSFC)

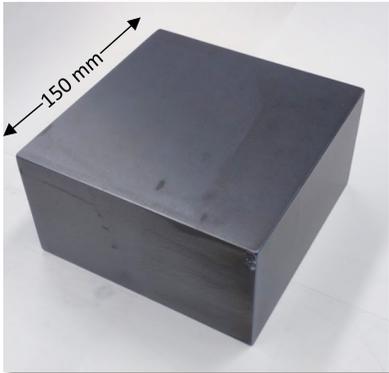
Direct polished mono-crystalline silicon



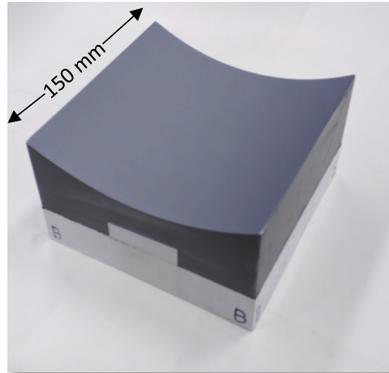
Parameters	Values
Total Number of Segments	37,492
Total Number of Meta-Shells	12
Radius (mm)	120 (Inner) – 1500 (Outer)
Segment Size (L x H) (mm)	100 x 100
Thickness Inner/Outer (mm)	0.5
Total mirror assembly mass (kg)	1,185 (including straylight & thermal baffles + structures)



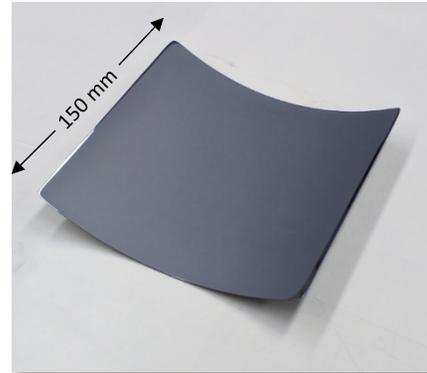
MAJOR STEPS OF SUBSTRATE FABRICATION



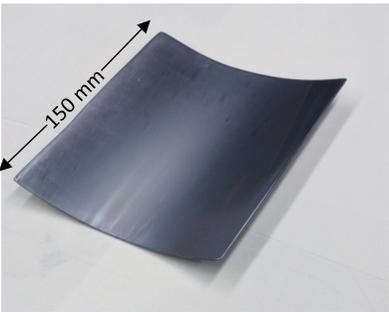
1. Mono-crystalline silicon block



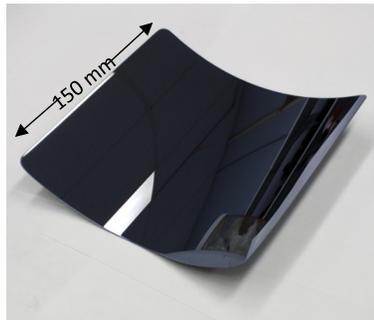
2. Conical form generated



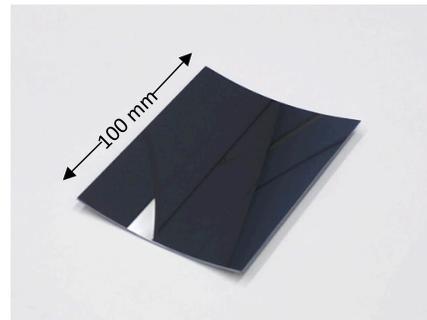
3. Light-weighted substrate



4. Etched substrate



5. Polished mirror substrate



6. Trimmed mirror substrate

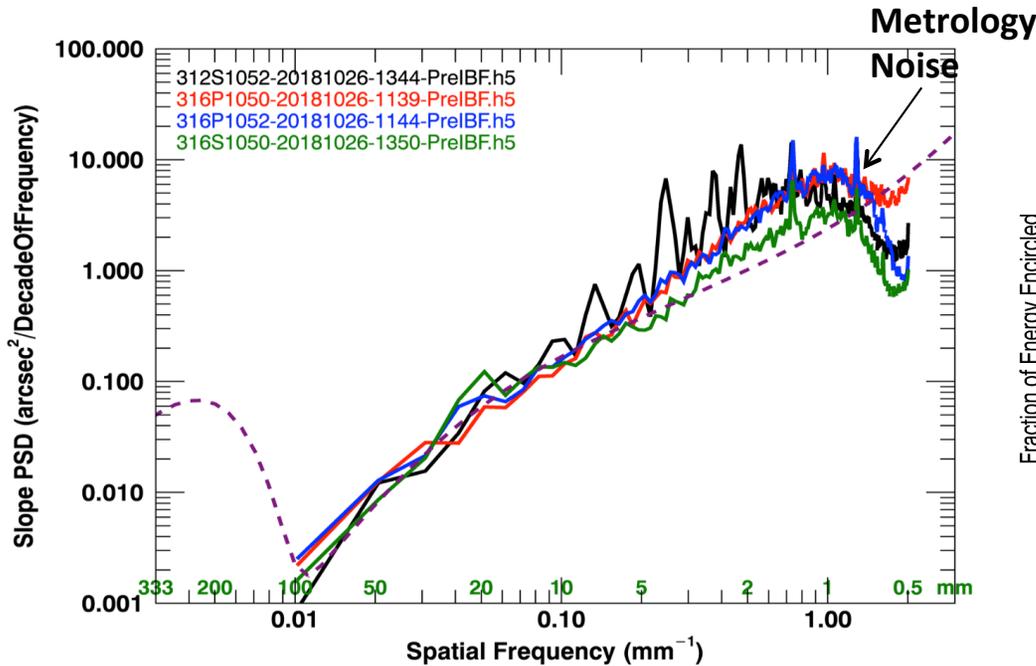
Key Features:

1. Use only **commercially** available equipment & materials.
2. Highly amenable to **automation** and **parallel** production.
3. Calendar Time: **5 days.**
4. Labor Time: **~15 hours.**



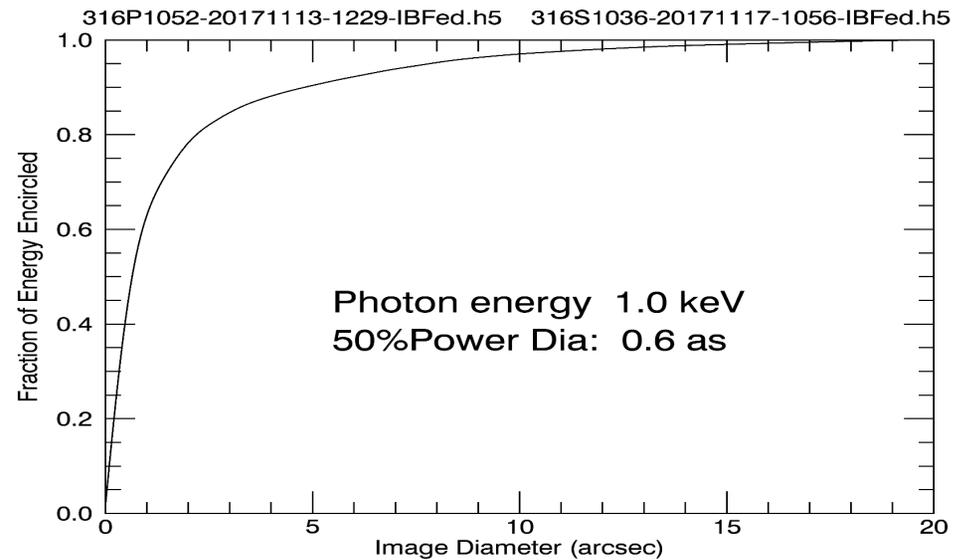
MANY MIRRORS MADE IN 2018 – METROLOGY LIMITED!

Measured Performance



Quality comparable to or slightly better than Chandra's mirror.

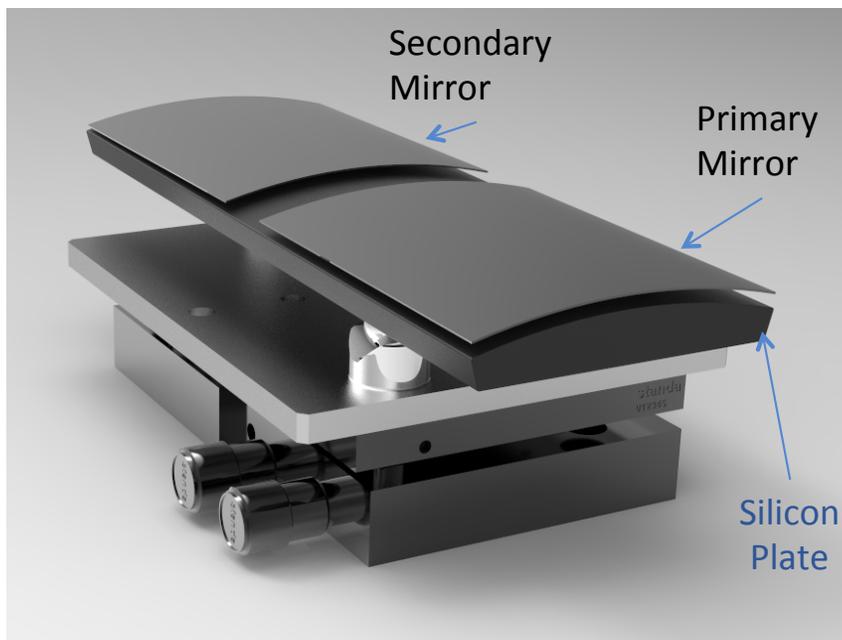
Predicted Performance



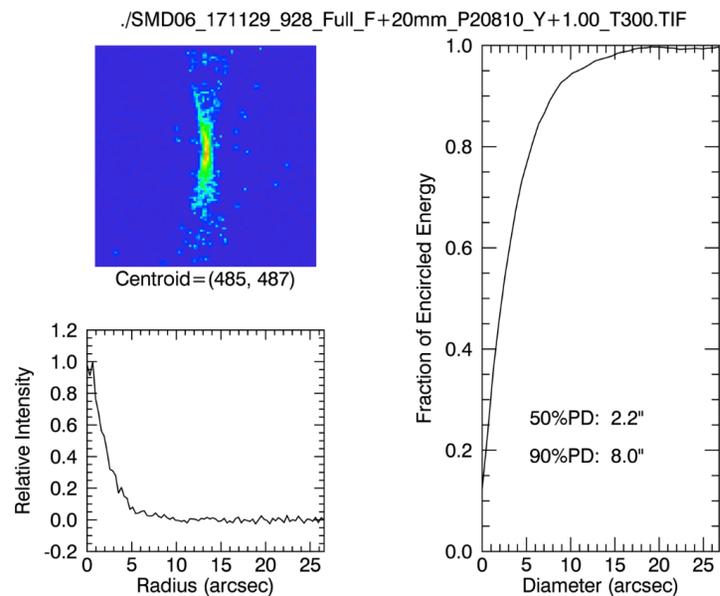
A good indication that mirrors can be made to meet Lynx (0.5" HPD) requirements.



X-RAY TESTING OF A PAIR OF MIRRORS



Two uncoated mono-crystalline silicon mirrors aligned and bonded on a silicon platform



Full illumination with Ti-K X-rays (4.5 keV)



SUMMARY AND GOALS

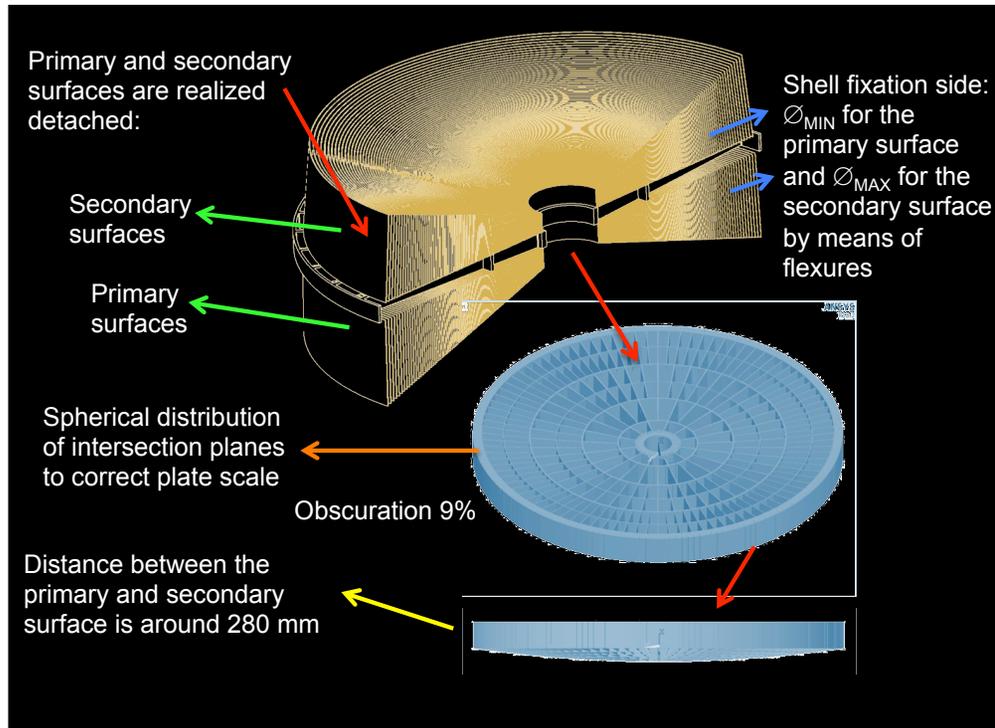
- 2012-2016: from a blue-sky idea to a practical process
 - Proof of principle, validating the approach based on precision-polishing of mono-crystalline silicon.
- 2017: Made **sub-arcsec mirrors** with thickness about *~1mm*.
- 2018: Made **sub-arcsec mirror** with thickness *~0.5mm*.
- 2019-2023(?): from **sub-arc-second** to **diffraction-limited** mirrors (*~0.1 arc-seconds*)
 - Continue to refine **fabrication** process and to understand and improve **measurement** process to make ever better mirrors: **0.3"** (2019), **0.2"** (2021), and **0.1"** (2023).



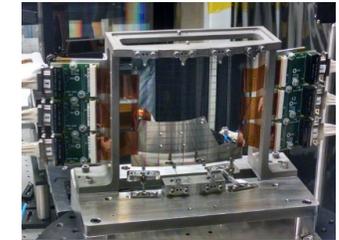
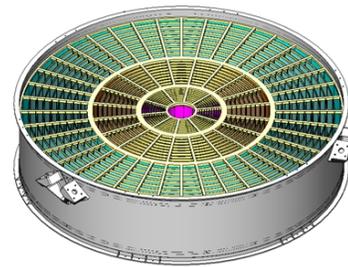
MULTIPLE FUNDED ON-GOING EFFORTS- FULL SHELL & ADJUSTABLE OPTICS

- G.Pareschi, M.Civitani, S.Basso & INAF Team (INAF-OAB)
- K. Kiranmayee, J. Davis, R. Elsner D. Swartz & MSFC Team (MSFC/USRA)

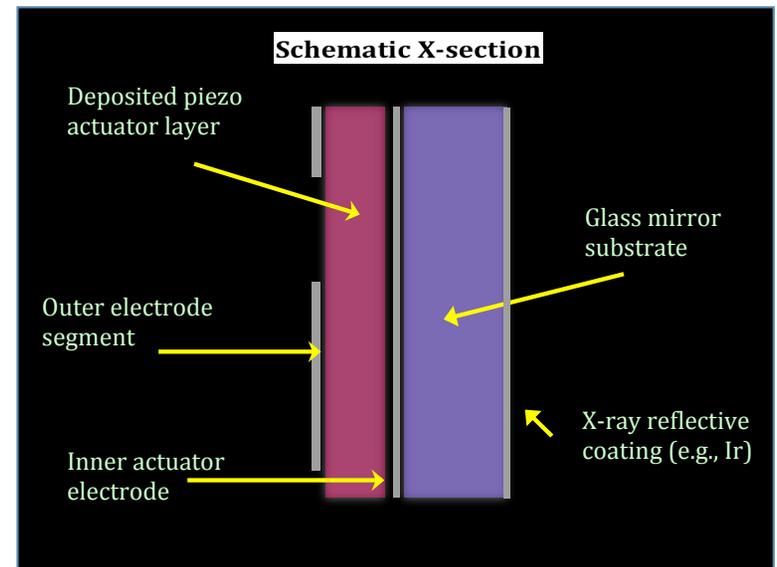
Direct Polished Fused Silica or Similar



- P. Reid
- SAO Adjustable Optics Team
- PSU Adjustable Optics Team



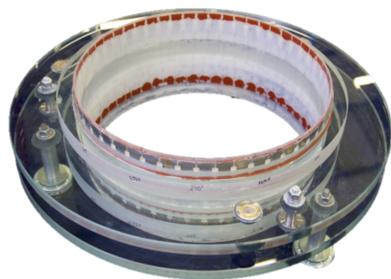
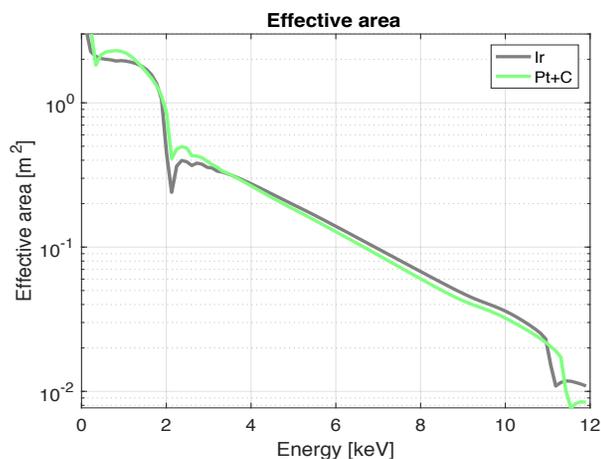
Slumped glass with sputter deposited piezoelectric material





FULL SHELL OPTICS

- M.Civitani, G. Vecchi, J. Holysko, S.Basso, M.Ghigo, G.Pareschi, (INAF-OAB)
- G.Parodi (BCV progetti), G.Toso (INAF-IASF)
- K. Kiranmayee, J. Davis, R. Elsner D. Swartz (MSFC/USRA)



Parameters	Values
Gap @ IP (mm)	280
Shift IP (*) (mm)	2.3 (Inner) – 124.7 (Outer)
Total Number of Shells	164 (x2 Primary + Secondary)
Radius (mm)	203.2 (Inner) – 1483.8 (Outer)
Semi-Shell height IP (mm)	157.9 (Inner) - 348.2 (Outer)
Thickness IP Inner/Outer (mm)	1.6 – 3.4
Total mirror assembly mass (kg)	1,890.7 986.3 Primary 904.4 Secondary
Mirror support structures & thermal control (*estimate*) (kg)	300 (TBC)



INAF-BRERA PROCESS

Step

Procurement of the fused silica shell

Annealing

Chemical etching

Mounting the shell in a Shell Supporting System

Fine grinding

Bonnet polishing

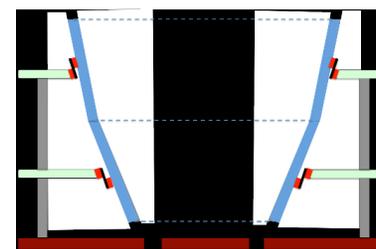
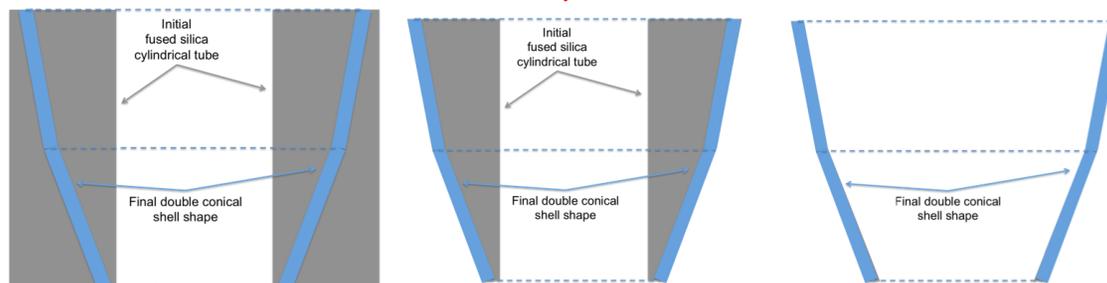
Pitch polishing

Ion beam figuring

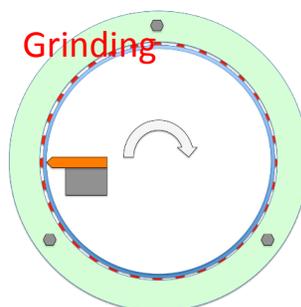
Coating

X-ray calibration

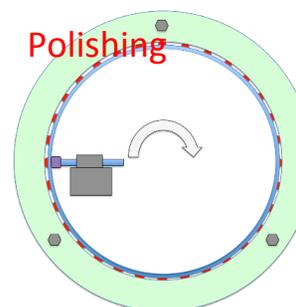
Raw shell production



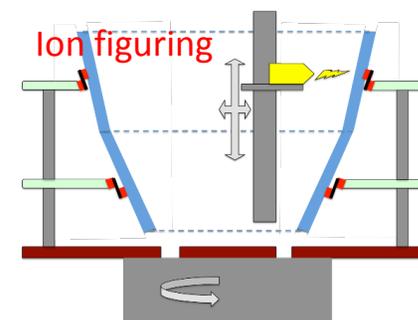
Fixation in a supporting system



Grinding



Polishing



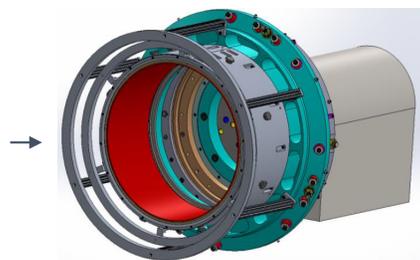
Ion figuring



MSFC FULL SHELL OPTICS FABRICATION PROCESS



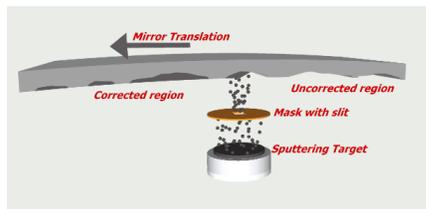
Machined mirror blanks



Diamond turning
TRL~2



Computer controlled polishing
TRL~3



Differential deposition
TRL~3



Low-stress reflective
coatings
TRL~3



Alignment and module integration
TRL~3

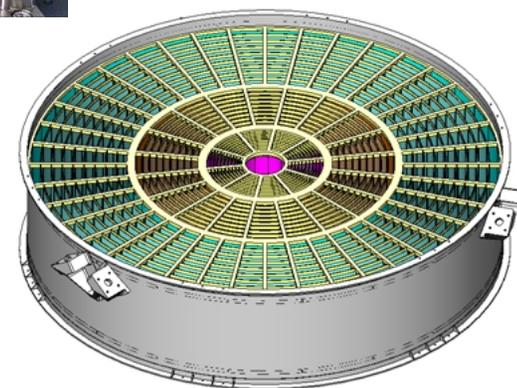
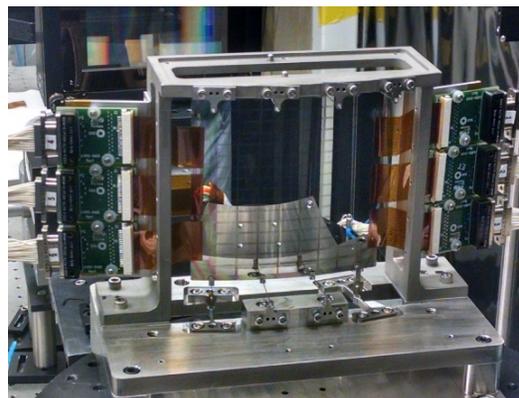


ADJUSTABLE OPTICS

- P. Reid
- SAO Adjustable Optics Team
- PSU Adjustable Optics Team

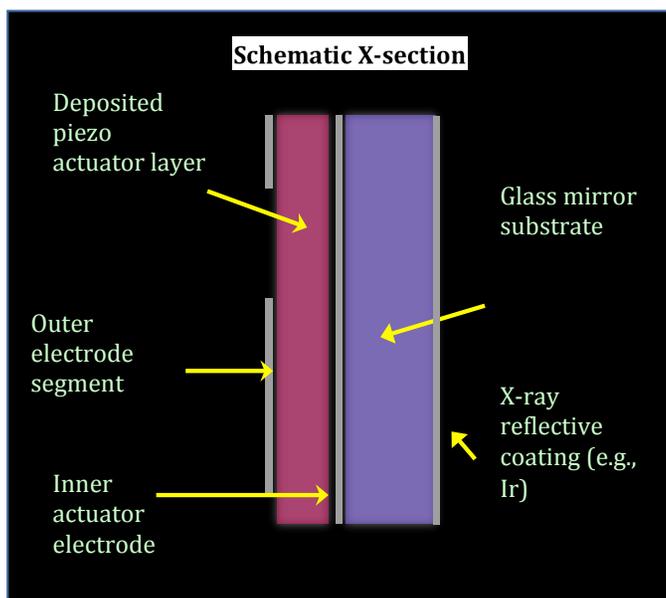
Parameters	Values
Total Number of Segments	12,720
Total Number of Shells	265
Number of Piezoelectric adjuster cells per mirror segment	~1500
Number of strain gauges per segment	~10
Radius (mm)	200 (Inner) – 1500 (Outer)
Segment Size (L x H) (mm)	200 x 220 – 200 x 120
Thickness Inner/Outer (mm)	0.4
Total mirror assembly mass (kg)	1,580 (includes pre- and post-thermal collimators)

Slumped glass with sputter deposited piezoelectric material

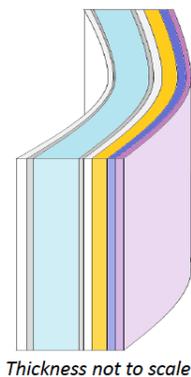




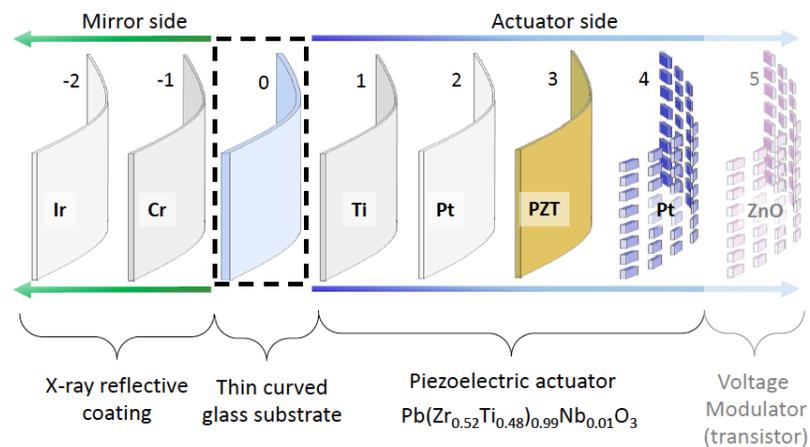
ADJUSTABLE OPTICS PROCESS



a) Multilayer mirror



b) Layers of the mirror





THE TIME FOR LYNX IS NOW!

Enabling Technologies TRL Assessment Summary

At Decadal Studies Management Team request, the ExEP, PCOS, and COR Program Offices and the Aerospace Corp assessed the TRL of tech gaps submitted by the teams as of Dec. 2016. Assessment was presented June 2017.

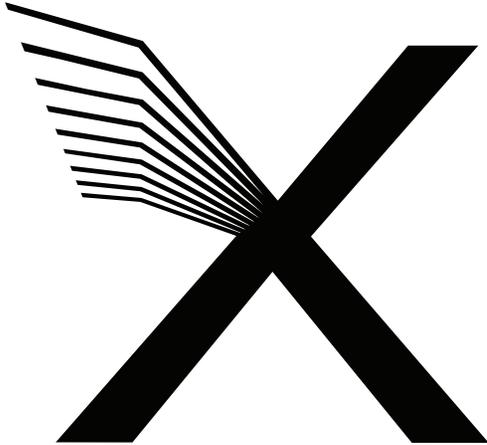
ID	Technology Gap	TRL
1	High-Resolution 'Lightweight' Optics	2 3
2	Non-deforming X-ray Reflecting Coatings	3
3	Megapixel X-ray Imaging Detectors (HDXI)	3
4	X-ray Grating Arrays (XGS)	4
5	Large-Format, High Spectral Resolution X-ray Detectors (LXM)	3

**Multiple Technologies
3-4+ by mid-2020**

**Multiple Technologies
Multiple Technologies**

Subsystem Heritage

THANK YOU!



Jessica.Gaskin@nasa.gov

Lynx Websites:

<https://www.wastro.msfc.nasa.gov/lynx/>

<https://www.lynxobservatory.com/>

